JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**

IOM 312.F-98-022

February 11, 1998

TO: Distribution

FROM: P.W. Chodas

SUBJECT: Small-Body Ephemeris Partials File

Reference: Chamberlin, A.B., "Small-Body Ephemeris NAVIO File Format - Version 2", JPL IOM 312.F-98-004, January 7, 1998.

Overview

A new type of file called the **Small Body Ephemeris Partials (SBP)** file is now available for use in the ODP/DPTRAJ suite of navigation programs. This NAVIO formatted file contains coefficients for Chebyshev polynomials which approximate the partial derivatives of asteroid and/or comet states with respect to their epoch state orbital parameters, as well as other dynamical parameters. The file is designed to be used in conjunction with the Small Body Ephemeris (SBE) file (see Reference), and is analogous to the Planetary Ephemeris Partials file and the Satellite Ephemeris Partials file. Unlike the planetary files, however, the SBE and SBP files can support a virtually unlimited number of bodies. Use of these new small body files has many advantages over the old procedure of creating special versions of the planetary ephemeris/planetary partials files and storing the small body data in the slot for Pluto. It is hoped this old practice will now be quickly phased out.

Contents of the Small Body Ephemeris Partials (SBP) File

The partial derivatives represented in the SBP file are the partials of the small body state (in units of km and km/s) with respect to either the Brouwer and Clemence Set III parameters, as used in the Planetary Partials file, or the set of Keplerian orbital parameters used by the Comet and Asteroid Ephemeris Team (e, q, T_p, Ω, ω, and i). The parameter names stored in the file indicate which set of epoch parameters is used for each body. Partials with respect to other dynamical parameters such as cometary nongravitational parameters A_1 and A_2 may also be included. The nongravitational parameters are essential in the orbital modeling of many comets. (The partial derivatives will then form a 6 by 8 Jacobian matrix rather than the usual 6 by 6 matrix.)

The partials on the SBP file are represented in much the same way as on the Planetary Ephemeris Partials file, viz. via piecewise continuous Chebyshev polynomials. For each small body, the time span of the file is split into small intervals of specified size, typically 8, 16, or 32 days. An approximating polynomial is formed over each interval and the coefficients are stored on the file. The interval size and number of coefficients in the polynomial is fixed for each small body, but may vary from one body to another on the same file. Each body's coefficients are stored in a separate NAVIO item. One restriction of the SBP file is that the partials for all bodies must be represented

over the *same* time interval; the planetary and satellite partials files also require this, but the latest version of the SBE file allows for different time intervals for different bodies.

Unlike the planetary partials file, the epoch of the Set III or Keplerian parameters can be individually set for each body. In particular, it is not restricted to the special Julian date of 2440400.5 (June 28, 1969) used for the planetary partials. Note that for an encounter with a small body, it is often desirable to use an epoch close to the encounter date.

Both the SBP and SBE files include the official IAU name and number for the body, as well as the JPL-assigned SPICE identification number. If the IAU has not assigned a name to the object, its official designation is used, and if the object has not been assigned a number, a zero is used. Thus, if an SBE and/or SBP file is created for an unnumbered or unnamed object, it is possible that these fields could change values in later versions of the files. In contrast, the SPICE object number (typically 7 digits) is intended to be a unique and unchanging identifier for an object.

Ancillary information provided on the SBP file (e.g., orbit solution identifiers, conversion factors, etc.) is very similar to that in the SBE file. A detailed description of the SBP file is attached, and is available on the web at "http://ssd.jpl.nasa.gov/JPL/sbp_file.html". The detailed description for the SBE file was given in the Reference, and is available on the web at "http://ssd.jpl.nasa.gov/JPL/sbe_file.html".

A reader for the SBP file is available in the "ephreaders" library of the ODP/DPTRAJ software suite, under the name SBPRDR.

Small Body Ephemeris Partials File Generation

SBP files are generated by the Comet and Asteroid Ephemeris Team using the program SBPGEN. Inputs to this program are typically placed in a varlist input file (essentially a namelist file). The orbital initial conditions are obtained from an ORB file, which archives all orbital solutions for the small body. The user can request that a particular orbital solution be used, or accept the default of using the latest orbital solution. (The solution identifier is written to the SBP file for traceability.) From the ORB file, SBPGEN extracts the Keplerian orbital elements for the specified solution, along with other dynamical parameters. It then converts the elements to a state, and numerically integrates the state forward or backward to the epoch requested for the partials. It generates an initial Jacobian matrix for the partials with respect to the desired epoch parameters (Set III or Keplerian), and then numerically integrates the variational equations forward and/or backward to cover the time span requested for the SBP file. As it integrates, the program saves the partial derivatives at evenly-spaced times, and when enough saved points are available, it fits a Chebyshev polynomial of specified order to the points and writes the coefficients to the SBP file.

SBPGEN handles only one body at a time, but it will merge its output into an existing SBP file if one is specified, so that a multi-body file can be built up one body at a time.

Distribution:
C.H. Acton
P. Antresian
S. Bhaskaran
W.E. Bollman
P.J. Breckheimer
D.V. Byrnes
J.K. Campbell
A.B. Chamberlin
J.E. Eklund
J. Ellis
J.D. Giorgini
G.R. Hintz
R.A. Jacobson
M.S. Keesey
V.N. Legerton
J.P. McDanell
P.R. Menon
J.K. Miller
T.D. Moyer
W.M. Owen, 3rd
J.E. Riedel
R.B. Roncoli
E.M. Standish
L.R. Stavert
F.M. Stienon
R.F. Sunseri
S.P. Synnott
W.L. Taber
R.C. Wang
B.G. Williams
R.N. Wimberly
L.J. Wood
D.K. Yeomans

Small Body Ephemeris Partials File

VERSION 2.0 - February 1998

General Description

The Small Body Ephemeris Partials File contains coefficients for Chebyshev polynomials which approximate partial derivatives of asteroid or comet states with respect to epoch state orbital parameters for the small bodies. The file may contain partials for many small bodies, although all the partials are represented over a single common time interval. The epoch state parameters may be either the six Brouwer and Clemence Set III parameters denoted DMW, DP, DQ, EDW, DA, and DE, or the classical orbital elements e, q, Tp, Ω, ω, and i. Partials with respect to other dynamic parameters such as cometary nongravitational parameters A1 and A2 may also be included.

Volume

The size of the file is dependent upon the number of small bodies represented on the file, length of the time interval covered by the file, the number of partials represented for each small body, the number of coefficients used for each partial, and the size of the time interval covered by each set of coefficients. A file covering a period of 6 years for a single small body, with a 32-day interval and 10 coefficients per partial is about 100K bytes in size.

Organization

The Small Body Ephemeris Partials file is written in NAVIO format.

Storage Medium

The file is stored on disk.

Program Usage

The Small Body Ephemeris Partials file is generated by the program **SBPGEN**. The partial derivatives of each small body's heliocentric Cartesian state parameters with respect to the epoch state parameters are first computed at epoch. These partials are then mapped forward and/or backward in time by numerically integrating the variational equations of motion. The resulting Jacobian matrix is sampled over each interval and Chebyshev coefficients are generated for each element of the Jacobian and written to the file. Several programs in the Navigation Software sets DPTRAJ and ODP read the file.

Detailed Description

ID Group

This group contains information used to identify the file, the programs used to create the data in the file, and the time interval covered by the file.

Item	Type	No. of Records	Max. Length	Direct Access
FILE-NAME	C*24	1	1	true
FILE-ID	C*80	1	1	true
PROGRAM-NAME	C*12	1	1	true
NAME-LENGTH	I	1	1	true
EQUINOX	D	1	1	true
START-EPOCH	C*25	1	1	true
START-JED	D	1	1	true
STOP-EPOCH	C*25	1	1	true
STOP-JED	D	1	1	true
FINGERPRINTS	C*80	var	1	true

Item	Description
FILE-NAME	The name of the file format: 'SMALL BODY PARTIALS FILE'.
VERSION	File version number, currently 2. The absence of this item indicates version 1.
FILE-ID	This will be an ID for the small body partials file that may include the small body ephemeris ID as well as an ID for the partials, e.g., 'SBP-A433P-35'.
PROGRAM-NAME	The name of the generating program, e.g., 'SBPGEN'.
NAME-LENGTH	The number of characters reserved for parameter names on the file; typically this is 16.
EQUINOX	The Julian date of the equinox used in the generation of the file. This will be either 2433282.50D0 (for EME1950) or 2451545.0D0 (for J2000).
START-EPOCH	The start time of the interval over which partials are represented on the file, expressed as a calendar date/time in TDB. Equivalent to START-JED in the same group. Example: "15-AUG-1999 01:01:54.1234" Note: All bodies represented on the file have the same START-EPOCH and STOP-EPOCH.
START-JED	The starting epoch of the interval over which partials are represented on the file, expressed as a Julian Ephemeris Date (JED). Equivalent to START-EPOCH.
STOP-EPOCH	The end time of the interval over which partials are represented on the file, expressed in the same calendar date/time format as START-EPOCH. Equivalent to STOP-JED in the same group.
STOP-JED	The ending epoch of the interval over which partials are represented on the file, expressed as a Julian Ephemeris Date (JED). Equivalent to STOP-EPOCH.
FINGERPRINTS	Fingerprints records of the programs which have written or updated the file. Each record contains the name of the program, e.g., 'SBPGEN' , the date/time of the program execution, the link date/time when the generating

program was created, and the name of the body whose partials were written or updated.

SMALL-BODY Group

This group contains information describing the small bodies on the file. The first item, NBODIES, gives the number of bodies on the file, and all the other items in this group contain NBODIES records, one for each of the bodies. The data for each body includes the official IAU number and name, the JPL (NAIF) object number, the an orbital solution identifier, the epoch of the partials for the body, and the epoch state of the body. The 'short name' defined in this group is used in the POLYNOMIAL group as the name of the item containing the Chebyshev coefficients. Note also that the epoch of the partials can vary from one body on the file to another.

Item	Type	No. of Records	Max. Length	Direct Access
NBODIES	I	1	1	true
IAU-NUMBER	I	NBODIES	1	true
OBJ-NUMBER	I	NBODIES	1	true
OBJ-NAME	C*56	NBODIES	1	true
SHORT-NAME	C*12	NBODIES	1	true
OBJ-TYPE	C*8	NBODIES	1	true
SOLUTION-ID	C*20	NBODIES	1	true
CREATE-TIME	C*25	NBODIES	1	true
DE-USED	C*10	NBODIES	1	true
EPOCH	C*25	NBODIES	1	true
EPOCH-JED	D	NBODIES	1	true
EPOCH-STATE	D	NBODIES	6	true
GM	D	NBODIES	1	true
AU	D	NBODIES	1	true

Item	Description
NBODIES	The number of small bodies represented on the file.
IAU-NUMBER	The official IAU number assigned to the small body, e.g. 243 for asteroid 243 Ida, or 1 for comet 1P/Halley. Note that these numbers are unique only within bodies of the same type (asteroid or comet); for example, there is both an asteroid 1 (Ceres) and a comet 1 (Halley). Furthermore, if the IAU has not assigned a number to the object, this field will have a value of zero.
OBJ-NUMBER	A unique integer number assigned to the small body by JPL and used to identify the body within the NAIF software set, e.g. 2000433 for asteroid 433 Eros. For numbered asteroids, OBJ-NUMBER is often set to 2000000 + the IAU number, but this is not always the case, and users should not attempt to derive the IAU number from the object number. For comets, OBJ-NUMBER is set to 1000000 + an arbitrary unique number unrelated to the IAU number.
OBJ-NAME	Official IAU name for the small body, if it has been assigned a name; otherwise the official IAU designation for the body. Official IAU names can be lengthy, can

	contain spaces, and usually contain both uppercase and lowercase letters; official designations often begin with year of discovery, and usually contain spaces.
SHORT-NAME	A short name for the body, no more than 12 characters in length, and unique at least within the file. This name will not contain embedded spaces or lowercase letters. Examples are 'MATHILDE', 'EROS', and 'WILD2'. SHORT-NAMEs are used as the names of the items in the POLYNOMIAL group containing the Chebyshev coefficients representing the partials for the small body.
OBJ-TYPE	A character string indicating the type of the object, either 'ASTEROID' or 'COMET'. Asteroids and comets may be included on the same NAVIO partials file.
SOLUTION-ID	A character identifier for the orbital solution used to generate the small body partials. This is often just a numeric string, but it may contain non-numeric characters.
CREATE-TIME	The time of creation of the partials coefficients for the body, represented as a calendar date/time string, e.g. "10-JUL-1997 04:05:06.1234".
DE-USED	The character representation of the JPL Development Ephemeris (DE) number for the planetary ephemeris used to generate CMOD's solution, e.g. "DE-0403", where 0403 specifies a particular ephemeris.
EPOCH	The epoch of the partials for the small body, represented as a calendar date/time string in TDB, e.g. "15-AUG-1999 01:01:54.1234".
EPOCH-JED	The epoch of the partials for the small body, expressed in Julian Ephemeris Date form.
EPOCH-STATE	Inertial-frame Cartesian heliocentric position and velocity of the small body at its epoch. The frame used is that of the planetary ephemeris identified in DE-USED. The units are AU and AU/d.
GM	The value of the gravitational parameter of the Sun, used to convert between state and classical or Set III elements. Units are AU^3/d^2.
AU	The length of the AU in kilometers, used for converting the partials from units of AU and AU/d to km and km/s, which are the numerator units of the output partials. The value of AU is obtained from the planetary ephemeris.

PARAMETER Group

This group contains the names of all the small body parameters on the file. These include the epoch orbital parameters with respect to which the partials are computed, along with possibly other dynamic parameters. The parameter names include suffixes to identify the small body. The nominal values for these parameters are also included in this group (although, note that the nominal values for Set III parameters are always zeroes).

Item	Type	No. of Records	Max. Length	Direct Access
NUMPAR	I	1	1	true
NAMPAR	C*16	1	NUMPAR	true
VALUES	D	1	NUMPAR	true

STATE-PTR	I	1	NBODIES	true

Item	Description
NUMPAR	The number of small body parameters whose names appear in item NAMPAR and whose nominal values appear in item VALUES.
NAMPAR	The names of small body parameters with respect to which partial derivatives are represented on the file. The maximum number of characters the parameter names may have is stored in item NAME-LENGTH of the ID group, and is nominally 16 characters, to match the large parameter set size limitation in the ODP. For each small body, the parameters are either heliocentric Set III parameters, (DMW, DP, DQ, EDW, DA, DE), or heliocentric Keplerian elements: eccentricity (EC), perihelion distance in AU (QR), time of perihelion passage in TDB Julian date form (TP), R.A. of the ascending node in degrees (OM), argument of perihelion in degrees (W), and inclination to the ecliptic in degrees (IN). Other dynamic parameters may be appended to the 6 orbital parameters: e.g., for a comet, the non-gravitational acceleration parameters A1 and A2 may be appended. (These are defined as the radial and transverse components of the nongravitational acceleration at 1 AU, in units of AU/d^2). To each parameter name is appended an underscore followed by an object identifier string. If the object is a numbered asteroid, the IAU number is appended: e.g., for asteroid 433 Eros, the Set III parameter names would be DMW_433, DP_433, DQ_433, EDW_433, DA_433, and DE_433. For a numbered comet, the character "P" for "Periodic comet" appears before the IAU number: e.g., for comet 81P/Wild 2, the Keplerian and nongrav parameter names would be EC_P81, QR_P81, TP_P81, OM_P81, W_P81, IN_P81, A1_P81, and A2_P81. If the object has no IAU number, the OBJ-NUMBER (typically 7 digits) is used as the suffix after the underscore (with no "P" for comets, since OBJ-NUMBER is unique). NAMPAR will be well-ordered in the sense that at least the 6 state names for a given body will be contiguous.
VALUES	These are the NUMPAR double precision nominal values for the parameters named in NAMPAR. Note that the nominal values for Set III parameters are zeroes.
STATE-PTR	An array of pointers, one for each body on the file, and in the same order as the records in SHORT-NAME. Each pointer is the index in NAMPAR of the 6 state parameters for the corresponding body.

POLYNOMIAL Group

This group contains the coefficients of the Chebyshev polynomials used to represent the partial derivatives of

the small body's heliocentric state at a given time with respect to the parameters given in NAMPAR. Other essential information is also given, such as the interval covered by each approximation, and the number of coefficients used. Items INTERVAL, NCOEFFS, and COEFF-PTR each contain one record per small body, with the records in the same order as the records of SMALL-BODY/SHORT-NAME. The Chebyshev coefficients themselves are stored in a separate item for each body, with the name of the item being that body's SHORT-NAME. Each of these items contains an ordered series of records, one per interval, running from the START-JED to or past the STOP-JED. The first two elements of each coefficients record are the start and stop times for the interval covered by that record.

Item	Type	No. of Records	Max. Length	Direct Access
INTERVAL	D	NBODIES	1	true
NCOEFFS	I	NBODIES	NUMPAR	true
COEFF-PTR	I	NBODIES	NUMPAR	true
Body Name	D	var	var	true

Item	Description
INTERVAL	The length of the time interval for the small body, in days. There is one record of Chebyshev coefficients per interval per body in this group. The interval should be a power of 2. There is a record for each small body on the file.
NCOEFFS	The number of coefficients used to represent the partial derivatives of the small body's heliocentric state with respect to each of the NUMPAR parameters on the file. If the body's state does not depend on parameter i of NAMPAR (i.e. if the partial derivative is identically zero), NCOEFFS(i) is zero. There is a record for each small body on the file.
COEFF-PTR	The starting locations in the coefficients records of the three coefficient sets for the partial derivative of the small body's heliocentric state with respect to each of the NUMPAR parameters on the file. If the body's state does not depend on parameter i of NAMPAR (i.e. if the partial derivative is identically zero), COEFF-PTR(i) is zero. There is a record for each small body on the file.
Body Name	The coefficients of the Chebyshev polynomial representing the partials of the small body heliocentric state in km and km/s, with respect to the parameters in NAMPAR (whose units are defined above). The names in item SMALL-BODY/SHORT-NAME are used as the item names in this group. For each body, there is one record per interval, beginning at START-JED and running through STOP-JED. The first two elements of each record are the beginning and ending times of the interval covered by the record, in JED form. These are followed by the coefficient sets, whose locations are given by COEFF-PTR. The number of double precision words in the coefficient set for the partial derivative of the three

components of heliocentric position with respect to parameter i is 3*NCOEFFS(i). Partial derivatives of the velocity components are computed by differentiating the polynomials for the position partials.

Last revision: 1998 Feb 11 (P.W. Chodas)